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STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. FRANK H. BIGELOW.

III.—THE OBSERVED CIRCULATION OF THE ATMOSPHERE IN THE HIGH AND LOW AREAS.

GENERAL DESCRIPTION OF THE VECTORS OBTAINED BY OBSERVATION.

In my original report on the cloud observations of 1896–97, it was necessary to present the data in such a form that other students could have the facts at first hand. As then pointed out there are several subareas in which only a few observations were located, and they are quite unevenly distributed about the central axis, so that the final vectors as computed do not have the well-balanced smoothness which it is desirable to obtain. The data was given in the form of tabulations and also of diagrams, since it is easier to secure from the latter a clear mental picture of the average configuration of the vectors of motion in all parts of the cyclones and anticyclones. Having done this at the outset I now proceed to draw up an average system of vectors by the process of graphic adjustment. There will still remain some uncertainty as to the finer details in certain areas where the motion is more complicated, but I am quite sure that the results presented in this paper give a very correct idea of the mean motions of the atmosphere over the United States and Canada. It would require a good deal more labor in observation and computation than was involved in a single year's campaign to bring the work to that degree of perfection which is desired by meteorologists; this work must undoubtedly be expended in the interest of science some time in the future. Especially for the higher strata of the high and low areas do we need more observations, because the powerful eastward drift quickly obscures the comparatively small gyratory components that penetrate up to the high levels. It should be remembered that the vectors in hand were procured by observing the motions of the air almost daily throughout the year, and consequently that all kinds of weather have entered our final results. If we want the characteristic circulation pertaining to well developed cyclonic and anticyclonic

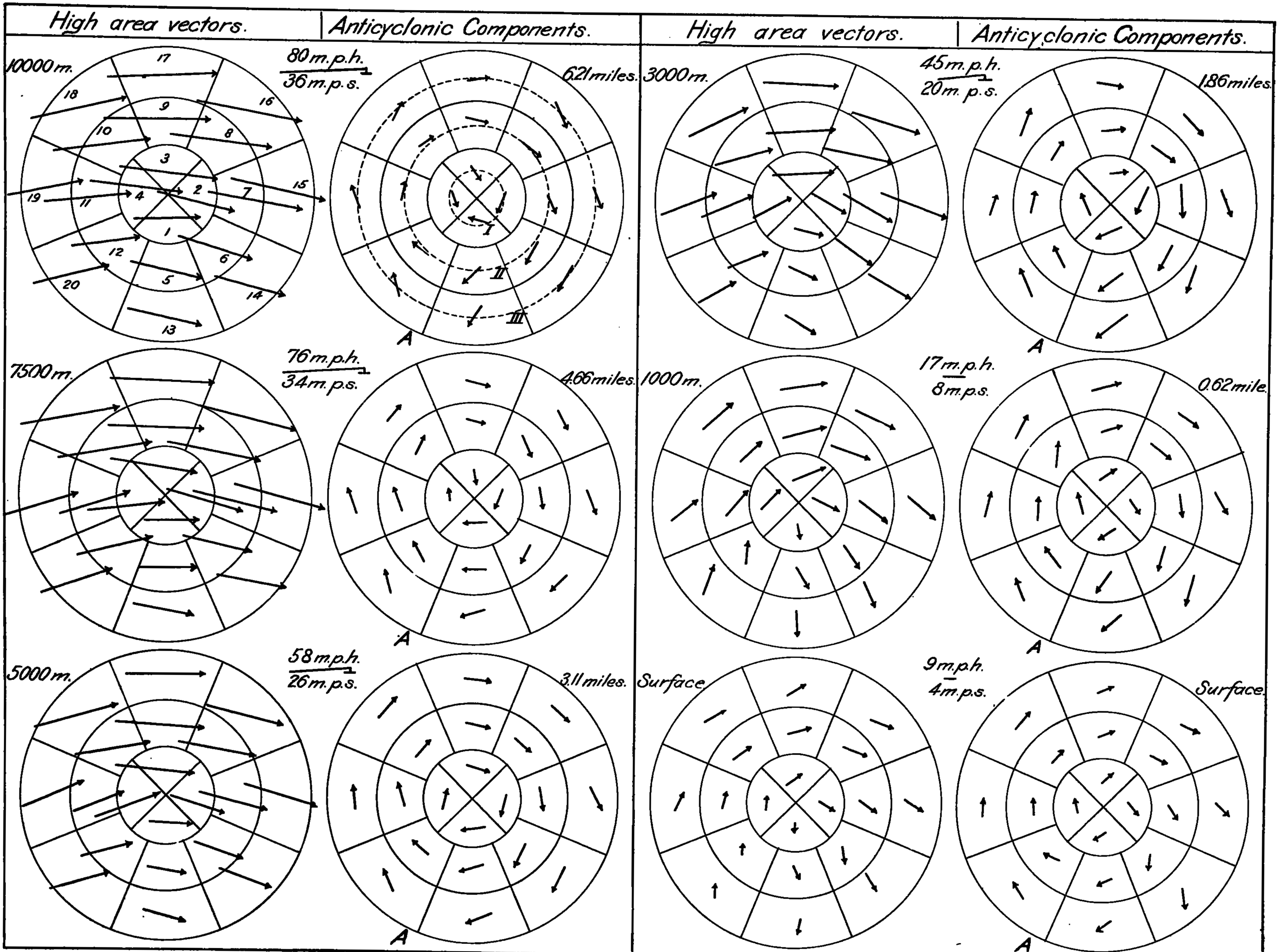

FIG. 6.—Adjusted mean vectors of direction and velocity of motion in high areas. 10,000 meters = 6.21 miles. Scale of distances, 1 cm. = 500 kilomters; velocities, 1 mm. = 2 meters per second. 1 meter per second = 2.24 miles per hour.

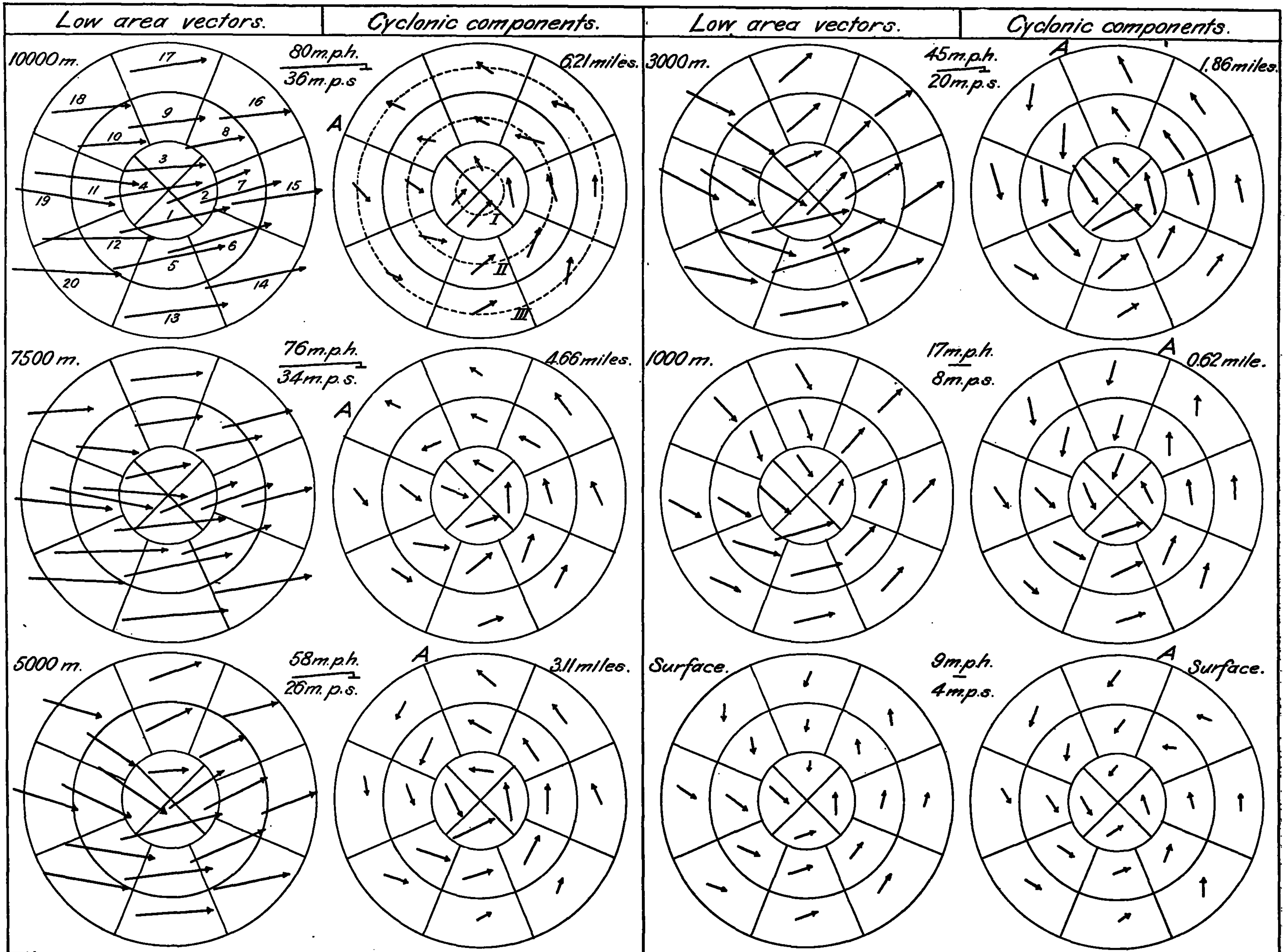

Fig. 7.—Adjusted mean vectors of direction and velocity of motion in low areas. 10,000 meters=6.21 miles. Scale of distances, 1 cm.=500 kilometers; velocities, 1 mm.=2 meters per second. 1 meter per second=2.24 miles per hour.

configurations, it can be found only by selecting the vectors on certain days when these types are strongly organized, and discussing them by themselves. Under the circumstances that pertained to the cloud year we were obliged to put every kind of observation together, without selection, and this necessarily produced many irregularities in the final scheme of vectors. I have now gone over the data again, and by studying the balance of the various parts of the system have brought out the revised scheme herewith presented. Its well-balanced symmetry speaks strongly for its average accuracy, and it will be possible to draw out of it many important conclusions of fundamental value for theoretical meteorology. We may remark that none of the principles enunciated in the original report have undergone modification by this present review.

By comparing the vectors of figs. 6 and 7 of this paper with Tables 34–47 and Charts 15 and 16 of the Cloud Report, one may readily examine all the changes that have been adopted, and may also discover how closely these charts represent the mean system indicated by the original observations. Instead of carrying the discussion through on the mean cloud levels where the observations were made, it is more convenient to select certain planes upon which the average vectors are established for further discussion.

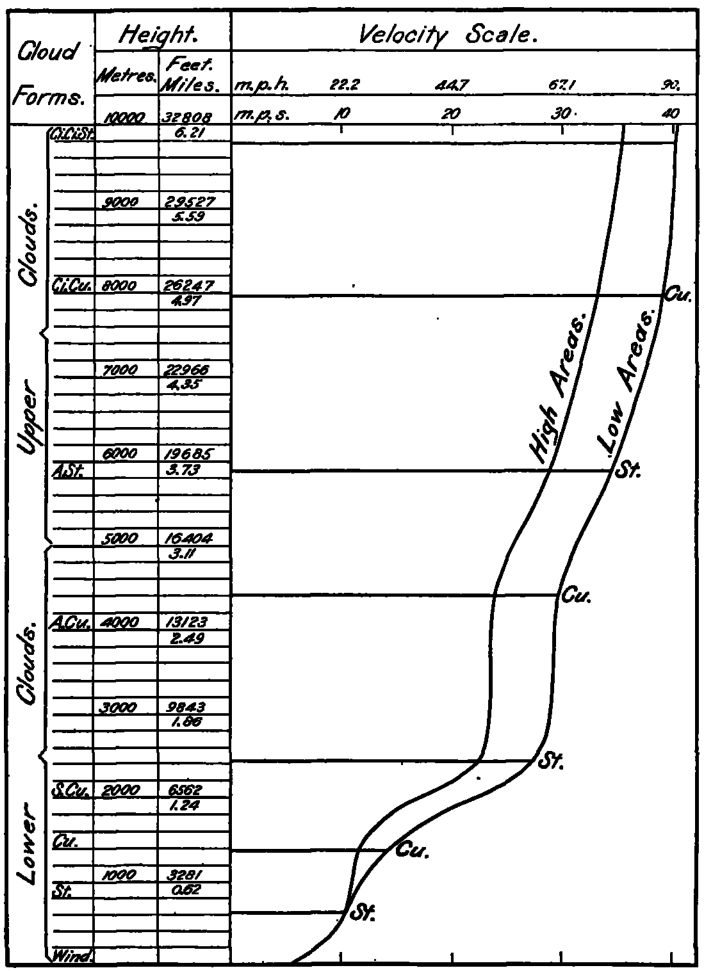

FIG. 8.—Total eastward velocities in high and low areas.

It is necessary first to establish the normal mean annual vectors representing the eastward drift to which the observed vectors are to be referred, in order to decompose them and obtain the anticyclonic and the cyclonic vectors by themselves. These normal vectors are given in Table 4, which is an extract from Table 33, III, International Cloud Report. The eastward velocities are also represented by fig. 8, total eastward velocities in high and low areas, which shows that the low areas drift eastward more rapidly than the high areas at all levels above the stratus, where they have about the same velocity, and that they drift northward in the United States, in the upper levels, at a somewhat higher velocity than in the low levels. It is important to bear in mind that the results of our observations pertain only to the central portions of the North American Continent, eastward of the Rocky Mountains, where the cyclonic storm tracks have on the average a northeastward direction toward the Gulf of St. Lawrence. On the Rocky Mountain slope they have a movement toward the south before recurving in the Mississippi Valley. Generally the eastward drift has a small northward or southward component varying in the different parts of the world, and it is not quite proper to draw general conclusions for the entire hemisphere from the motion of the atmosphere in one district. Furthermore, since the cyclonic areas have a special vortical progression of their own, it seems probable that the average velocities observed in the high areas represent the true motion of the total mass of circulating air more correctly than would the mean of the high and the low areas. The normal eastward and northward components have, therefore, been chosen a little in excess of those given by observation for the high areas, and they are given in Table 8.

TABLE 8.—*Normal component velocities on six selected planes.*

Height.	Eastward velocity.	Northward velocity.	Height.	Eastward velocity.	Northward velocity.
Meters.	*m. p. s.*	*m. p. s.*	*Miles.*	*m. p. h.*	*m. p. h.*
10,000	36	— 2	6.21	80	— 4
7,500	34	— 2	4.66	76	— 4
5,000	26	— 1.5	3.11	58	— 3
3,000	20	— 1	1.86	45	— 2
1,000	8	— 1	0.62	17	— 2
Surface	4	— 0.5	Surface	9	— 1

Two points may be noted in passing: (1) The eastward drift seems to be stratified into a series of steps by a decided change of the eastward velocity, and it appears that some form of stratus cloud is to be found at the bottom, and some form of cumulus cloud at the top, of each distinct stratum of flowing air. This indicates that at the surface of discontinuity between moving strata, the stratus type of cloud forms by a process of cooling through mixture from adjacent layers of air at different temperatures, which is in accord with general theory. It also shows that the cumulus clouds form by vertical convection and dynamic cooling within a stratum having about the same uniform velocity of motion throughout its mass and this is also theoretically correct. (2) The components of average total motion do not show that the atmosphere drifts northward in the higher levels and at the surface, and southward in the lower middle levels, somewhat elevated from the ground, as was claimed should be the case by Professor Ferrel in his canal theory of the general circulation of the atmosphere. I will return to this topic and consider it at length, but the fact here indicated is that the observations do not sustain that part of the general canal theory. It is becoming clearly demonstrated to students that the circulation of the air is a more complicated problem than the early meteorologists assumed, and in consequence it will be necessary to study in detail the stream lines over the several continents and oceans, find out their local characteristics, and after that try to combine them in a large comprehensive scheme.

DESCRIPTION OF THE CIRCULATION OVER HIGH AND LOW AREAS.

Figs. 6 and 7 represent the adjusted mean vectors of direction and velocity of motion in high and low areas, as derived from the Weather Bureau observations of 1896–97. They are based upon about 6,000 theodolite observations made at

Washington, D. C., and about 25,000 nephoscope observations made at 15 stations distributed quite uniformly over the territory east of the Rocky Mountains. They give only a mean or average scheme of the circulation and are necessarily somewhat idealized, as regards the movements of the air in individual configurations, since they include all the anticyclones and cyclones of the cloud year, many of which were only imperfectly developed, and could not have agreed with the best types that might have been selected. In order that no false impressions should remain with students concerning the actual circulation of the atmosphere, because of this construction of a well-balanced type, I compiled for the International Cloud Report a series of composite charts, Nos. 20 to 35, inclusive, which show the actual stream lines in high and low areas over the several areas of the United States, both for summer and winter. These charts are not only interesting, but they are very valuable, because they give the normal flow of the air when the anticyclonic and cyclonic centers are located in different parts of the country. They ought to be studied carefully by every forecaster, and the general knowledge given by the charts should be kept firmly in mind when considering the meaning of the individual daily weather maps, as they will guide the judgment to safer conclusions than would be possible without them. For the student of theoretical meteorology they are indispensable, because they correct the impressions which may be given by a contemplation of the figs. 6 and 7, or by reflecting upon the analytical formulæ.

DISCUSSION OF THE VECTORS IN HIGH AREAS.

The area about the center of circulation was subdivided into twenty small parts, numbered as already described in a previous paper; the upper left-hand plans of figs. 6 and 7 show them again for convenience of reference. Through the center of each of the three concentric groups a circle is drawn in dotted lines, and these are marked I, II, III, their distance from the center being 250, 750, 1,250 kilometers, respectively. The adopted heights of the planes of motion in meters and miles are written on each level, also the normal velocity vector in meters per second (m. p. s.), and miles per hour (m. p. h.). The scale of distances is 1 cm. = 500 kilometers, and the scale of velocities is 1 mm. = 2 meters per second; the latter can be reduced to miles per hour by multiplying with the factor 2.24. The left-hand plans contain the total vector as observed in the atmosphere; the right-hand plans give the component vector, which, combined with the normal vector, produces the observed vector, using the rule of the parallelogram of vectors. Each vector has been carefully constructed and deserves considerable confidence. The smoothly balanced configuration in each level and the gradual change which occurs in passing from one level to another show that this represents a natural and easy form of flow for the atmosphere, so that the motion will occur without sharp changes. The figures speak plainly for themselves, and only a few words are required regarding the distinguishing features. In the high areas the total flow diminishes in strength from 10,000 meters to the surface; it has a slight curvature northward over the center in the highest level, but this concavity of the curves gradually increases till in the lower levels and at the surface the sinuous lines are converted into anticyclonic gyrations. The vectors north of the center are longer than those south of it from the top to the bottom. There is, however, a strong eastward drift in all levels, inward on the west side and outward on the east side, which is never overcome.

Passing now to the anticyclonic component vectors, it is noted that there is a remarkable symmetry in the configuration from the highest level to the lowest, taken as a whole. There are, however, two special features to be observed: (1) In the central areas, I, the flow is inward on the highest level, more from the north, however, than from the south; it is tangential on the middle level; and it is outward in the lowest level. This indicates a type of true vortex motion, which prevails at the center of anticyclones, and by it the air is drawn in at the top and discharged at the bottom of the vortex tube. (2) On the middle areas, II, the flow is nearly tangential throughout the entire series of strata, but on the outer areas, III, the vectors are pointed slightly outward from the top to the bottom, though more strongly on the east side than on the west side. There is, furthermore, the special feature that at the south or southwest side of the anticyclonic area, near the place marked *A*, a distinct discontinuity occurs in the vectors, by which on the west side an inflow from the south takes place, and on the east side an outflow from the north is indicated. I interpret these two facts together to mean that in the southeast quadrant there is a tendency for a heavy stream of the general circulation from the northwest to divide, so that a large portion moves to the south side of the adjacent cyclonic area and a small portion curls westward about the center of the high area. Also, on the west side of the high area a stream from the south divides, part flowing over the north of the high area and another part curling about the north side of the center of the adjacent low area. Fig. 9, Curling of the northward and southward streams about the centers of high and low areas, gives an idea of this process, especially in the strato-cumulus level, or at about 3,000 meters elevation. The heavy broken line represents the resulting sinuous eastward flow at that level. In the flow of fluids a wave motion, when the velocity exceeds a given amount, collapses and reappears in the form of whirls of discontinuous surfaces along the sides. Something of this sort is apparently operating in this connection.

We observe that in the 3,000-meter level the anticyclonic vectors are stronger than in the levels above or below, the diminution toward the surface being greater than toward the higher levels. The superposition of the component gyration upon the eastward drift is distinct and even vigorous at 10,000 meters, and hence it is inferred that the disturbance of the atmosphere in high areas extends to at least 6 or 8 miles, though only as a small deflection of the eastward drift in the upper strata.

DISCUSSION OF VECTORS IN LOW AREAS.

The vectors in the low areas should in general be a little longer than those in the high areas. In nature the highs cover a larger territory than do the lows, but as the amount of air which streams through each of them is probably about the same, it would require a greater velocity in the lows to produce an equal discharge through them. The vectors flow southward relatively to the center, and they are larger on the southern side than on the northern. The connection of the streams between the high and low areas is shown by the smooth flow of the two sets of vectors on their eastern and western sides, respectively. The stream lines are convex upward, and the curvature increases from the 10,000-meter level to the surface. In the 1,000-meter level the gyratory movement nearly supersedes the sinuous or wave-like flow, but the vectors on the north side are not entirely reversed to the westward.

The cyclonic components are very symmetrically formed throughout the entire stratum of air that has been examined. They have the following characteristic, namely, that from the surface to the 10,000-meter level the vectors have an inflow toward the center, except in a few subareas marked with the letter A. It is noted that from the 10,000-meter level to the 1,000-meter level, near the place A, the vectors are almost exactly opposed to each other in direction, those on the east side flowing outward and those on the west side flowing inward. This divergence of direction indicates that a stream flows from the north to the south on the west of the low area, and that an independent stream flows northward on the east side of the low area, something in the manner suggested on fig. 9. The

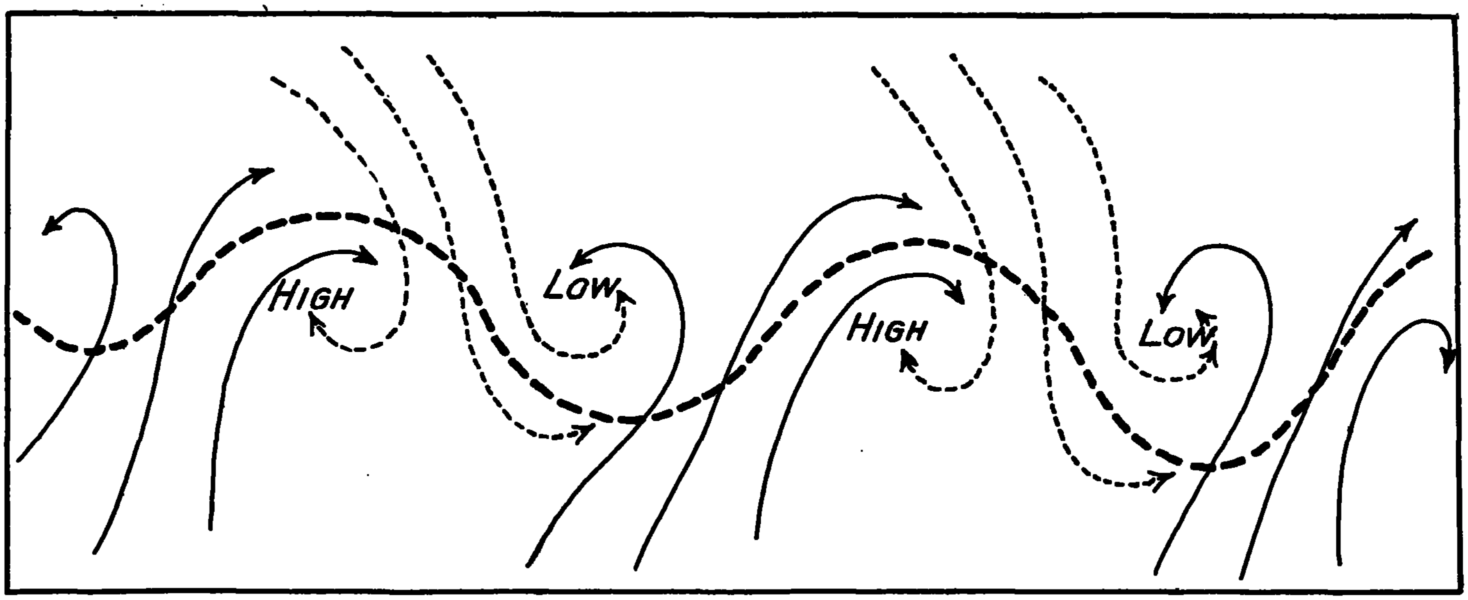

FIG. 9.—Curling of the northward and southward streams about the centers of high and low areas.

separate streams from the north and from the south coalesce on the south side of the center of the low area, as they do on the north side of the high area, but the two streams have an origin *outside* the areas of high and low pressure, respectively. Furthermore, it is noted that while in the high area the position of the point A is nearly stationary in all the strata mapped out, on the contrary it rotates nearly 90° from the east of north at the surface to the north of west in the highest stratum. The stream of warm air from the south curls around toward the west as it ascends from the surface to the upper levels, making a quarter of a helical revolution in an ascending spiral. The length of the vectors is greatest in the 3,000-meter level, 2 miles above the ground, and the vectors become gradually shorter upward and downward, diminishing more rapidly toward the surface. This agrees with the system of vectors in high areas, and shows that the influence of the cyclone extends above the 10,000-meter level, where it still deflects considerably the eastward drift, though it is most vigorous in the 3,000-meter level. The length of the vectors increases gradually from the III-areas to the I-areas, and averages about twice as long in the latter as in the former. In the anticyclonic components the III-vectors are even longer than the I-vectors, and they do not have any agreement with the simple vortex law $\varpi\,\omega =$ constant, where ϖ is the radial distance from the axis of rotation, and ω the angular velocity.

In the cyclonic components the I-vectors are longer than the III-vectors, but they fall short of exact conformity with the pure vortex theory. The entire flow suggests, therefore, the conflict of two counterflowing, horizontal streams which tend to produce vertical rotation, but in fact fail to reach this ideal, except possibly in highly developed cases of severe storms. There is no evidence that these motions are primarily

TABLE 9.—*Rectangular and cylindrical coordinates in high areas.*

Direction from center.	Area number.	10,000 meters.				7,500 meters.				Distance from center.
		u_1	v_1	u_2	v_2	u_1	v_1	u_2	v_2	
S	1	− 2	+29	− 2	− 6	+ 2	+24	+ 2	−10	I. 250 km.
E	2	+ 6	+31	− 4	− 6	+ 8	+30	− 4	− 8	
N	3	+ 6	+40	− 6	− 5	+ 6	+36	− 6	− 2	
W	4	+ 4	+39	− 3	+ 5	− 4	+32	+ 2	− 4	
S	5	+ 8	+28	+ 8	− 8	0	+24	0	−10	II. 750 km.
SE	6	+10	+30	+ 2	− 9	+ 8	+30	+ 3	− 9	
E	7	+ 7	+40	+ 4	− 7	+ 8	+36	+ 2	− 8	
NE	8	+ 6	+43	+ 2	− 7	+ 8	+38	− 4	− 8	
N	9	+ 2	+44	+ 2	− 8	+ 4	+40	− 4	− 6	
NW	10	− 4	+40	− 2	− 6	− 8	+38	+ 4	− 8	
W	11	− 4	+36	− 1	− 4	−10	+30	+ 4	−10	
SW	12	− 5	+28	0	− 7	− 8	+30	− 4	− 8	
S	13	+ 8	+30	+ 8	− 6	+ 4	+24	+ 4	−10	III. 1,250 km.
SE	14	+ 9	+28	+ 2	− 9	+ 6	+28	0	− 9	
E	15	+ 9	+40	+ 4	− 9	+10	+38	+ 4	−10	
NE	16	+10	+42	− 4	−10	+ 9	+40	− 4	− 8	
N	17	− 2	+44	+ 2	− 8	+ 3	+42	− 3	− 8	
NW	18	− 8	+40	+ 4	− 8	− 6	+40	+ 1	− 8	
W	19	− 8	+32	+ 4	− 8	− 9	+30	+ 4	− 9	
SW	20	− 8	+32	− 4	− 6	− 8	+28	− 6	− 8	

TABLE 10.—*Rectangular and cylindrical coordinates in low areas.*

Direction from center.	Area number.	10,000 meters.				7,500 meters.				Distance from center.
		u_1	v_1	u_2	v_2	u_1	v_1	u_2	v_2	
S	1	−10	+46	−10	+10	− 6	+46	− 6	+12	I. 250 km.
E	2	−12	+34	− 2	+12	−12	+32	− 2	+12	
N	3	− 4	+32	+ 4	+ 4	− 6	+26	+ 6	+ 8	
W	4	− 6	+40	− 6	− 4	+ 4	+44	−10	+ 4	
S	5	− 8	+44	− 8	+ 8	−10	+44	−10	+10	II. 750 km.
SE	6	−12	+42	− 5	+14	−12	+34	− 6	+10	
E	7	−10	+32	− 4	+10	−10	+30	− 4	+10	
NE	8	− 4	+24	− 4	+12	− 6	+26	− 4	+ 9	
N	9	− 6	+32	+ 4	+ 6	− 4	+28	+ 4	+ 6	
NW	10	− 3	+30	+ 6	+ 3	+ 4	+26	+ 4	+ 8	
W	11	+ 6	+44	− 6	+ 8	+ 8	+42	− 8	+ 8	
SW	12	+ 2	+46	− 6	+ 8	0	+46	− 7	+10	
S	13	− 4	+44	− 4	+ 8	− 4	+42	− 4	+ 8	III. 1,250 km.
SE	14	− 8	+40	− 4	+ 8	− 8	+38	− 4	+ 8	
E	15	− 6	+36	0	+ 6	− 8	+30	− 4	+ 8	
NE	16	− 4	+28	− 4	+ 8	− 8	+28	+ 2	+10	
N	17	− 4	+30	+ 4	+ 6	− 4	+30	+ 4	+ 4	
NW	18	− 4	+30	+ 6	+ 4	− 2	+28	+ 6	+ 2	
W	19	+ 6	+42	− 6	+ 6	+ 6	+40	− 6	+ 6	
SW	20	+ 4	+42	− 4	+ 6	+ 4	+40	− 2	+ 7	

TABLE 9.—*Rectangular and cylindrical coordinates in high areas*—Cont'd.

Direction from center.	Area number.	5,000 meters. u_1	v_1	u_2	v_2	3,000 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	+2	+18	+2	-8	+4	+12	+4	-8	I. 250 km.
E	2	+8	+22	-2	-8	+8	+16	-4	-8	
N	3	+4	+34	-4	-8	-2	+26	+2	-6	
W	4	-8	+28	-2	-8	-8	+16	+4	-8	
S	5	+4	+16	+4	-10	+6	+14	+6	-6	II. 750 km.
SE	6	+8	+20	+4	-8	+12	+14	+4	-12	
E	7	+8	+28	+2	-8	+10	+20	0	-10	
NE	8	+6	+32	0	-8	+6	+28	+2	-10	
N	9	+3	+34	-3	-8	-2	+28	+2	-8	
NW	10	-6	+30	+1	-7	-8	+24	+2	-10	
W	11	-8	+24	+2	-8	-8	+24	-4	-8	
SW	12	-6	+20	0	-8	-6	+14	-4	-8	
S	13	+4	+16	+4	-10	+8	+10	+8	-10	III. 1,250 km.
SE	14	+8	+22	+4	-8	+10	+16	+5	-11	
E	15	+8	+30	+4	-8	+10	+26	+6	-10	
NE	16	+7	+32	0	-10	+10	+28	-2	-12	
N	17	0	+36	0	-10	+2	+30	-2	-10	
NW	18	-9	+32	+1	-11	-12	+24	+4	-12	
W	19	-10	+24	+2	-10	-10	+24	-4	-10	
SW	20	-8	+22	-4	-8	-8	+14	-4	-10	

Direction from center.	Area number.	1,000 meters. u_1	v_1	u_2	v_2	Surface. u_1	v_1	u_2	v_2	Distance from center.
S	1	+4	+2	+4	-6	+3	0	+3	-4	I. 250 km.
E	2	+6	+12	+4	-6	+3	+7	+3	-3	
N	3	-6	+14	+6	-6	-4	+7	+4	-3	
W	4	-8	+6	+2	-8	-5	+2	+2	-5	
S	5	+8	+4	+8	-4	+3	+1	+3	-3	II. 750 km.
SE	6	+10	+6	+6	-8	+4	+2	+4	-4	
E	7	+8	+10	+2	-8	+6	+8	+4	-6	
NE	8	+6	+16	+6	-8	+4	+10	+2	-7	
N	9	-4	+16	+4	-8	-3	+10	+3	-6	
NW	10	-8	+10	+1	-9	-5	+8	0	-6	
W	11	-10	+8	0	-10	-6	+2	+2	-6	
SW	12	-8	+2	-2	-10	-3	0	+2	-5	
S	13	+8	0	+8	-8	+4	-1	+4	-5	III. 1,250 km.
SE	14	+10	+4	+6	-9	+7	+5	+6	-4	
E	15	+8	+14	+6	-8	+6	+9	+5	-6	
NE	16	+8	+16	+2	-11	+4	+10	+2	-7	
N	17	-4	+18	+4	-10	-4	+8	+4	-4	
NW	18	-10	+12	+4	-10	-6	+8	+1	-7	
W	19	-10	+10	-2	-10	-7	+4	0	-7	
SW	20	-10	+4	-4	-10	-5	-1	-2	-5	

$+u_1$ = southward. $+v_1$ = eastward. $+u_2$ = radial outward. $+v_2$ = tangential counter clockwise.

due to vertical convective currents developed through the local heating or cooling of restricted areas near the center of the cyclonic and anticyclonic areas, respectively. It is evidently desirable to avoid extreme statements in this connection, because a study of the motions of the atmosphere shows that nearly every possible type of motion from the counterflow of opposing horizontal streams to the pure vortex due to an ascending helix may occur, and yet the present compilation indicates that the former is the average type to which the stream lines conform in the extra-tropical circulation of the United States.

TABLE 10.—*Rectangular and cylindrical coordinates in low arean*—Cont'd.

Direction from center.	Area number.	5,000 meters. u_1	v_1	u_2	v_2	3,000 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	-10	+42	-10	+16	-10	+40	-10	+20	I. 250 km.
E	2	-16	+22	-4	+16	-18	+16	-4	+18	
N	3	-2	+16	+2	+10	-8	+12	+8	+6	
W	4	+14	+28	-6	+14	+16	+28	-8	+16	
S	5	-4	+36	-4	+10	-10	+32	-10	+12	II. 750 km.
SE	6	-14	+32	-5	+14	-12	+26	-6	+12	
E	7	-12	+24	-2	+12	-14	+24	-4	+14	
NE	8	-10	+20	+4	+12	-12	+12	+4	+14	
N	9	-10	+18	+6	+10	-12	+14	+6	+12	
NW	10	+12	+20	-6	+12	+12	+18	-7	+10	
W	11	+12	+30	-4	+12	+16	+22	-2	+16	
SW	12	+4	+38	-4	+12	+12	+32	0	+18	
S	13	-4	+32	-4	+6	-6	+28	-6	+8	III. 1,250 km.
SE	14	-6	+30	-4	+6	-8	+26	-2	+10	
E	15	-8	+22	-4	+8	-10	+18	-2	+10	
NE	16	-6	+22	+2	+7	-10	+14	+4	+10	
N	17	-8	+20	+6	+8	-12	+14	+12	+6	
NW	18	+6	+22	-2	+7	+10	+18	-6	+8	
W	19	+8	+28	-2	+8	+12	+24	-4	+12	
SW	20	+4	+34	-4	+8	+4	+28	-4	+8	

Direction from center.	Area number.	1,000 meters. u_1	v_1	u_2	v_2	Surface. u_1	v_1	u_2	v_2	Distance from center.
S	1	-6	+24	-6	+16	-4	+10	-4	+6	I. 270 km.
E	2	-8	+4	-4	+8	-6	0	-4	+6	
N	3	+10	+4	-10	+4	+4	-2	-4	+6	
W	4	+10	+12	-4	+10	+8	+8	-4	+8	
S	5	-4	+20	-4	+12	-4	+10	-4	+5	II. 750 km.
SE	6	-10	+12	-4	+10	-6	+6	-2	+6	
E	7	-10	+6	-2	+10	-6	+2	-2	+6	
NE	8	-10	+8	+8	+6	-4	-2	-2	+4	
N	9	+10	+4	-10	+4	+4	-2	-6	+4	
NW	10	+12	+4	-6	+10	+6	+2	-4	+5	
W	11	+8	+14	-6	+8	+6	+8	-4	+6	
SW	12	+8	+20	-4	+14	+4	+10	-2	+8	
S	13	-4	+18	-4	+10	-4	+8	-4	+4	III. 1,250 km.
SE	14	-10	+10	-2	+10	-6	+4	-4	+4	
E	15	-8	+8	0	+8	-6	+4	0	+6	
NE	16	-8	+10	+8	+4	-4	-2	-2	+4	
N	17	+10	+6	-10	+2	+4	-2	-6	+4	
NW	18	+10	+8	-9	+4	+6	0	-4	+6	
W	19	+8	+14	-6	+8	+6	+8	-4	+6	
SW	20	+6	+14	0	+8	+3	+8	-2	+5	

$+u_1$ = southward. $+v_1$ = eastward. $+u_2$ = radial outward. $+v_2$ = tangential counter clockwise.

THE NUMERICAL VALUES OF THE VECTORS.

In order to bring out these facts a little more clearly, the vectors of fig. 6 have been translated into the numerical values of Table 9, Rectangular and cylindrical coordinates in high areas; and those of fig. 7 into the numbers of Table 10, Rectangular and cylindrical coordinates into low areas. These tables need no further explanation in this connection, after what has been already stated.

Table 11, Mean components on the I, II, III circles in meters

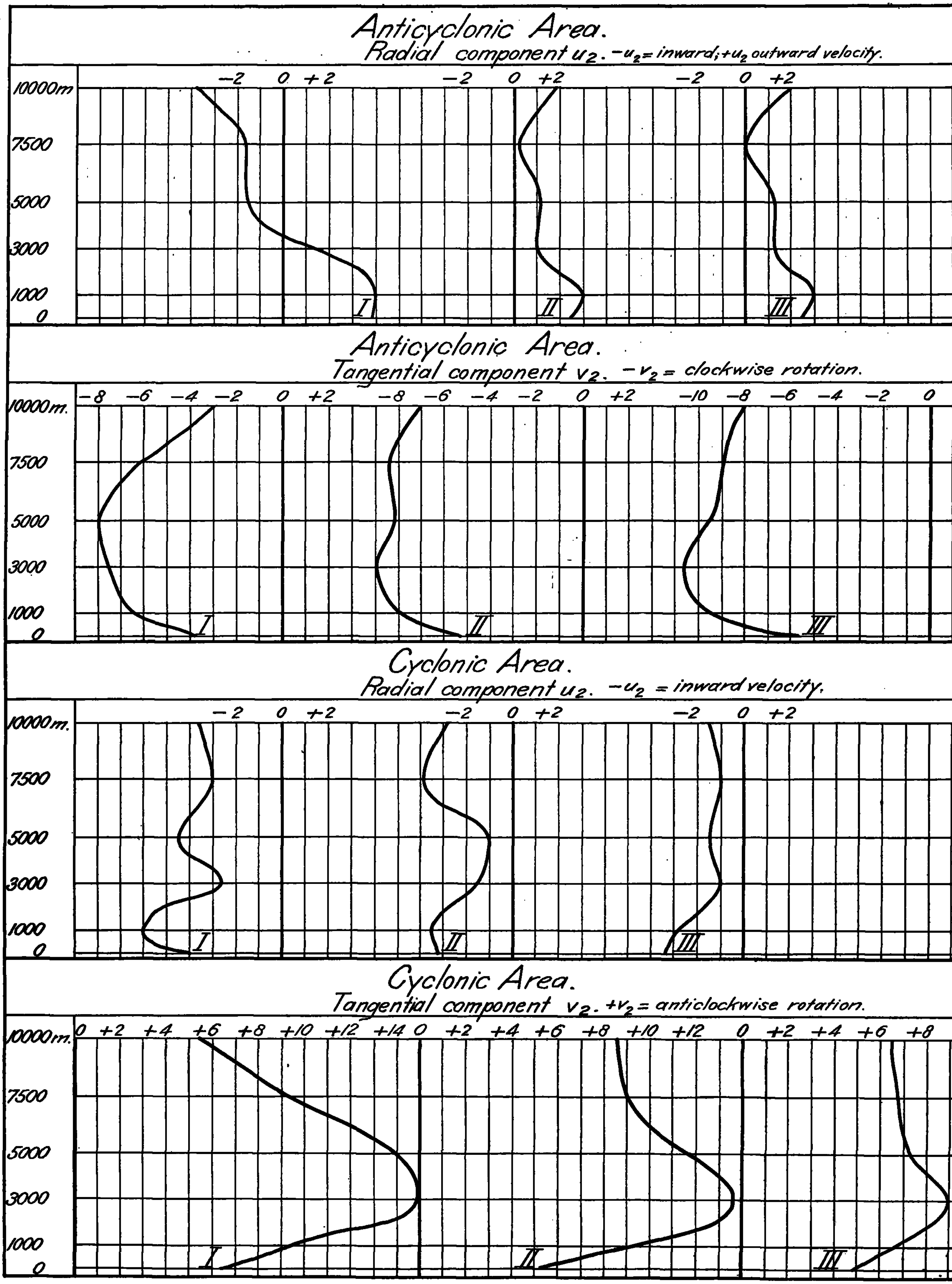

FIG. 10.—Radial and tangential components in anticyclonic and cyclonic areas. From Table 11.

per second and in miles per hour, is derived from the anticyclonic components of Table 9, and the cyclonic components of Table 10, by taking the arithmetical mean of the I-areas (1–4), the II-areas (5–12), and the III-areas (13–20). These means give the average value of the motion, though we, of course, depart from the perfectly natural condition by the summation. Thus in the anticyclonic areas for the radial component u_2 there is an inflow at the top of I-areas, and an outflow at the bottom; and a gentle outflow in the II-areas and III-areas from the top to the bottom. Also compare fig. 10, where the results of Table 11 are plotted. The tangential component v_2 is stronger throughout the middle strata than in those which are higher or lower, but it is much more vigorous in the III-areas than in the I-areas especially at the 3,000-meter level. In the cyclonic areas the radial component u_2 increases generally from the III-area to the I-area. There is a little irregularity in the changes of this component probably due to imperfections in my vector system. The tangential component v_2 increases rapidly from the III-areas to the I-areas, and remarkably so at the 3,000-meter level.

TABLE 11.—*Mean components on I, II, III circles.*

ANTICYCLONIC COMPONENTS.

Distance from center.	I. 250 kilometers.		II. 750 kilometers.		III. 1,250 kilometers.	
Meters per second.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	− 3.8	− 3.0	+ 1.9	− 7.0	+ 2.0	− 8.0
7,500	− 1.5	− 6.0	+ 0.1	− 8.4	0.0	− 8.8
5,000	− 1.5	− 8.0	+ 1.3	− 8.1	+ 1.4	− 9.4
3,000	+ 1.5	− 7.5	+ 1.0	− 9.0	+ 1.4	−10.6
1,000	+ 4.0	− 6.5	+ 3.1	− 8.1	+ 3.0	− 9.5
0	+ 3.0	− 3.8	+ 2.5	− 5.4	+ 2.5	− 5.6

CYCLONIC COMPONENTS.

Meters per second.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	− 3.5	+ 5.5	− 2.9	+ 8.6	− 1.5	+ 6.5
7,500	− 3.0	+ 9.0	− 3.9	+ 8.9	− 1.0	+ 6.6
5,000	− 4.5	+14.0	− 1.9	+11.8	− 1.5	+ 7.3
3,000	− 3.5	+15.0	− 2.4	+13.5	− 1.0	+ 9.0
1,000	− 6.0	+ 9.5	− 3.5	+ 9.3	− 2.9	+ 6.8
0	− 4.0	+ 6.5	− 3.3	+ 5.5	− 3.3	+ 4.9

ANTICYCLONIC COMPONENTS.

Distance from center.	I. 155 miles.		II. 466 miles.		III. 777 miles.	
Miles per hour.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	− 8.5	− 8.7	+ 4.3	−15.7	+ 4.5	−17.9
7,500	− 3.4	−13.4	+ 0.2	−18.8	0.0	−19.7
5,000	− 3.4	−17.9	+ 2.9	−18.1	+ 3.1	−21.0
3,000	+ 3.4	−16.8	+ 2.2	−20.1	+ 3.1	−23.7
1,000	+ 8.9	−14.5	+ 6.9	−18.1	+ 6.7	−21.3
0	+ 6.7	− 8.5	+ 5.6	−12.1	+ 5.6	−12.5

CYCLONIC COMPONENTS.

Miles per hour.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	− 7.8	+12.3	− 6.5	+19.2	− 3.4	+14.5
7,500	− 6.7	+20.1	− 8.7	+19.9	− 2.2	+14.8
5,000	−10.1	+31.3	− 4.3	+26.4	− 3.4	+16.3
3,000	− 7.8	+33.6	− 5.4	+30.2	− 2.2	+20.1
1,000	−13.4	+32.4	− 7.8	+20.8	− 6.5	+15.2
0	− 8.9	+14.5	− 7.4	+12.3	− 7.4	+11.0

It has been taught in the common expositions of the canal theory of the general circulation that there exists in middle latitudes a strong northward component in the upper strata, a strong southward component in the surface and lower strata, and a powerful eastward component in all strata, increasing from the ground upward. It can be seen by inspecting figs. 6 and 7 that while there is everywhere a general eastward drift, there are certain subareas over which especially a northward component prevails, and others over which there is a southward component. In order to find the maximum meridional components it is expedient to select the following areas for the northward component: Low (16, 8, 2, 7, 15, 6, 14) and High (18, 10, 11, 19, 12, 20), and for the southward component High (16, 8, 2, 7, 15, 6, 14) and Low (18, 10, 4, 11, 19, 12, 20). The values of u_1, v_1 are taken for these areas from Tables 9 and 10, and the mean of them is given in Table 12, Northward and southward velocities in selected areas. It can be seen at once that the general canal theory is by no means supported by the observations. The fact seems to be that between the high and low centers, west of the high and east of the low, there is a northward current in all levels, strongest at about the 3,000-meter level, while east of the high and west of the low there is a southward current also strongest in the

TABLE 12.—*Northward and southward velocities in selected areas.*

Height of the stratum.	Northward. L. 16, 8, 2, 7, 15, 6, 14. H. 18, 10, 4, 11, 19, 12, 20.		Southward. H. 16, 8, 2, 7, 15, 6, 14. L. 18, 10, 4, 11, 19, 12, 20.	
	u_1	v_1	u_1	v_1
10,000	− 6.4	+34.5	+ 4.4	+37.7
7,500	− 8.4	+31.9	+ 5.8	+36.2
5,000	− 9.1	+25.2	+ 8.1	+27.6
3,000	−10.3	+19.7	+10.6	+22.7
1,000	− 9.2	+ 7.9	+ 8.4	+11.7
Surface	− 5.2	+ 2.6	+ 5.3	+ 6.9

Compare Table 124, International Cloud Report, p. 606.

same level. The interchange of air between the pole and the Tropics appears, therefore, to be brought about by alternate currents in middle latitudes flowing past each other on the same levels, and not over each other at entirely different levels, as the canal theory requires. The thermal equilibrium of the air is, therefore, restored through the anticyclonic and cyclonic mechanism, and not by the overflowing currents from the Tropics to the poles and underflowing currents from the poles to the Tropics, as commonly taught. This profoundly modifies the canal theory of the general circulation of the atmosphere and introduces us to a new point of view. The discussion of the theories of the circulation of the air as explained by Ferrel, Oberbeck, and other meteorologists must be taken up next in order, and their views contrasted with the results of our observations.

FOG AND FROST FORMATION.

By DAVID CUTHBERTSON, Local Forecast Official.

An unusually dense fog, such as had not been observed for many years, occurred at Buffalo, N. Y., during the night of February 15 to 16, 1902. It was so remarkable for its great density and for the beautiful frostwork which formed on all sides of trees and other objects that it was a very common topic of conversation for days, and the local Weather Bureau